A Simple Transverse Motion Detector for Railguns

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This paper addresses the accurate measurement of the transverse armature-sabot motion during a railgun shot. One way to make such measurements is to use three orthogonally arranged piezorestive accelerometers made by ENDEVCO. Model 7270A-200k is a tiny unit rated for measurements up to 200 kGee. Each unit costs about $1,500 and has a specified 4-kGee uncertainty due to "non-linearity and hysteresis" and a 5 percent "transverse sensitivity." There are "Zero shifts"—an output voltage corresponding to 0 acceleration, and the unit can be highly susceptible to electromagnetic interference (EMI). Assuming a railgun-launched armature experiences a 10 percent transverse/longitudinal acceleration ratio, a 100-kGee axial launch will result in a transverse measurement uncertainty on the same order of magnitude as the measurement itself. Expense and measurement uncertainty are the principal liabilities of the piezorestive-accelerometer method for measuring transverse acceleration. The new method, below, addresses these liabilities.

A diagram of the new technique is shown in Figure 1. The idea is to *accurately* determine the independent transverse separations x_1 and x_2 (and related velocities dx_1/dt and dx_2/dt, and accelerations d^2x_1/dt^2 and d^2x_2/dt^2) by accurately measuring changing capacitances C_1, C_2. Dynamic analyses of the sabot material and geometry (e.g., using DYNA) can also be used to obtain a relatively accurate relationship between applied force and acceleration with separations x_i.

Four parallel-plate capacitors shown in the figure are each formed by using one rail for one of the plates and a small copper sheet on the sabot as the other. The two capacitors on the left side of the sabot are in series to form C_1. The inductor L_1 and capacitor C_1 comprise a high-Q tank circuit to tune oscillator circuit 1. A similar circumstance applies to C_2 and L_2 on the right. The two oscillation signals, having squared radian frequencies $\omega_1^2 = (C_1 L_1)^{-1}$ and $\omega_2^2 = (C_2 L_2)^{-1}$, are summed, delivered to an antenna, and allowed to propagate through the laminated containment. These signals may be received concurrently by fixed RF receivers and recorded by a LeCroy oscilloscope.

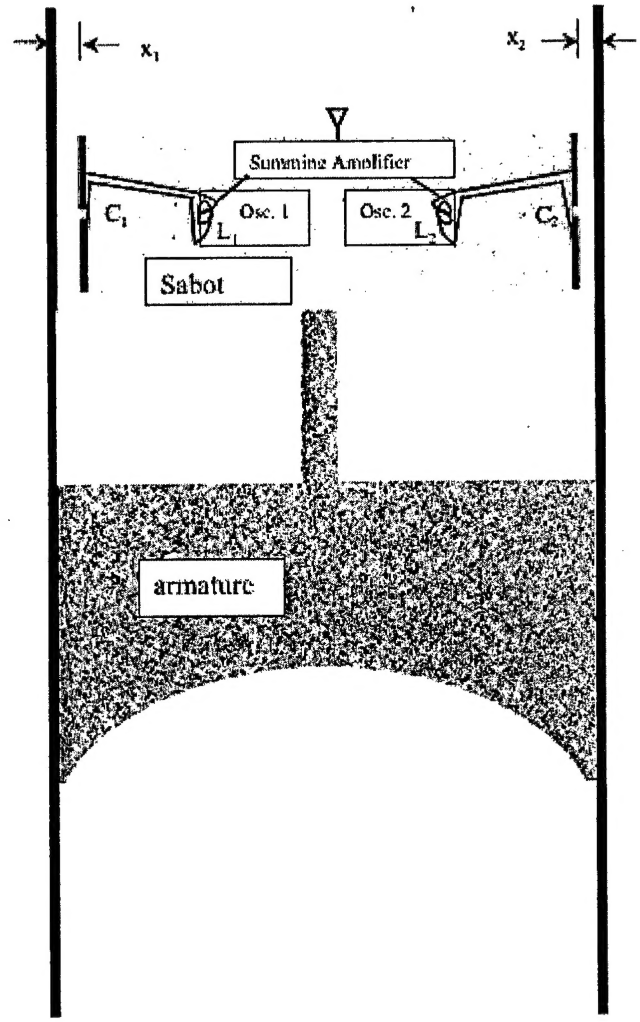

Figure 1. A diagram of the new technique.

The relationship of C_i with separation x_i (to first order) is $C_i = 0.5\varepsilon A/x_i$, where ε is the permittivity of air (8.85 pF/m), A is the cross-sectional area of the capacitor plate on the sabot, and x_i is the transverse plate separation—the desired measurement quantity. Nominal values are: x_i = 1 mm, A = 35 mm*35 mm => C_i = 5 pF. Small inductors (e.g., 10 turn coil radius = 3 mm, ~1 μH) can be oriented to minimize voltages induced by the low-frequency railgun B-field. Different constant inductor values (e.g., L_1= 1 μH, L_2 = 0.5 μH) result in different nominal signal frequencies for osc_1 (71 MHz) and osc_2 (100 MHz).

A simple, time-varying relationship between transverse sabot motion and frequency may be obtained by combining the two equations for C_i above to give:

$$x_i(t) = 0.5L\varepsilon A\omega_i^2(t).$$

Careful static measurements will provide a more accurate relationship between C_i and x_i (and between x_i and ω_i^2), but $x_i(t)$ remains directly proportional to $\omega_i^2(t)$. Since digital measurements on a LeCroy oscilloscope are resolved in time or frequency to within 10 ppm (i.e., $\Delta\omega/\omega < 10^{-5}$), the associated transverse position measurement uncertainties $\Delta x_i/x_i = \Delta\omega^2/\omega^2 < 10^{-10}$ would be minimal.

Even after mixing down the received signals (for example, to 1 MHz), the extraordinarily large number of time samples of x_i can be used to minimize errors associated with time derivatives of $x_i(t)$ for velocity and acceleration calculations.

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